

Novel Vortex States in a 3D Shape-Controlled Mesoscopic Superconductor

Scientific Achievement

Controlled-shape 3D mesoscopic superconductors where all three dimensions are comparable to the superconducting length scales λ (penetration depth) and ξ (coherence length) heralds a new paradigm to explore vortex confinement effects. In these electrochemically grown crystals, the surface and shape of the meso-crystals become the dominant factors which determine the stability of the vortex structure. We present ballistic micro-Hall probe magnetization measurements on a single mesoscopic crystal of Pb, shaped like a triangular prism with faceted edges. Magnetization measurements demonstrate the stability of high vorticity L states with single flux quanta entry and exit into the sample at low temperatures. In contrast, a clear Meissner state is observed at high temperatures with very stable low vorticity states. Our results indicate that these novel 3D-architected meso-superconducting crystals can be tuned to exhibit type I and type II behavior with temperature! A full 3D Ginzburg-Landau calculation predicts a novel phase consisting of Abrikosov vortices co-existing with a multi-quanta giant vortex state in these shaped crystals due to the strong effect of the confining geometrical shape on the vortex structure.

Significance

Our results demonstrate the rich spectrum of vortex states in a new class of 3D mesoscopic superconductors. The plethora of various shapes afforded by the electrochemical synthesis of these 3D mesoscopic superconductors provide a new platform to explore novel vortex confinement behavior such as the interaction of the vortex supercurrent with fractal boundaries in crystals with a snowflake geometry and the escape of a single quantum of flux from a multifaceted surface where the facet sizes are smaller than the superconducting penetration length. Furthermore, the sharp 3D vertex corners found in these mesocrystals will provide new insights to the nucleation of superconductivity and its resistance to high magnetic fields recently reported in 2D star-shaped samples.

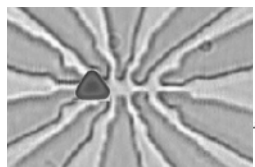
Performers

Andreas Rydh, Ruobing Xie, Michael Zach, Ulrich Welp, George W. Crabtree and Wai-Kwong Kwok (ANL-MSD)

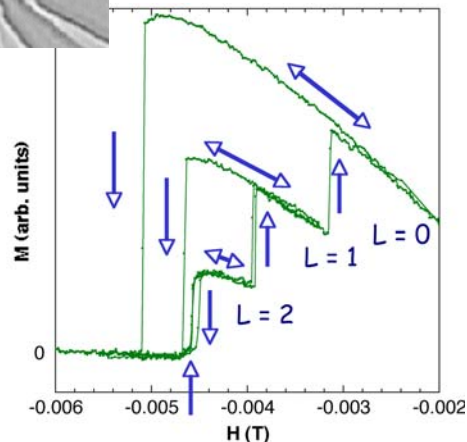
Simon Bending (University of Bath, UK)

M. Milosovec, F. Peeters (University of Antwerp, Belgium)

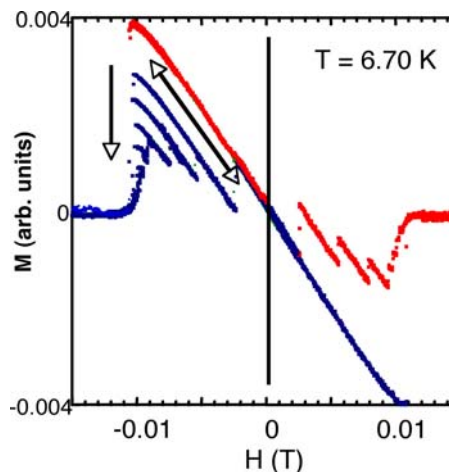
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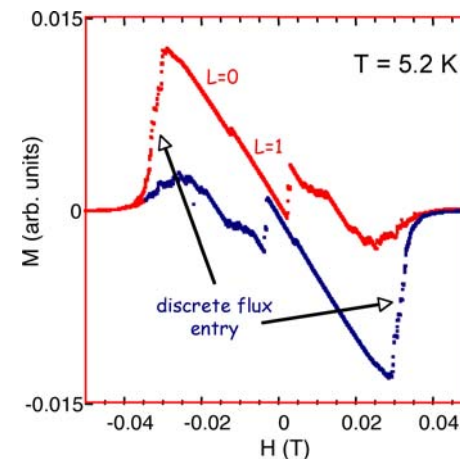
Meissner State
Type I



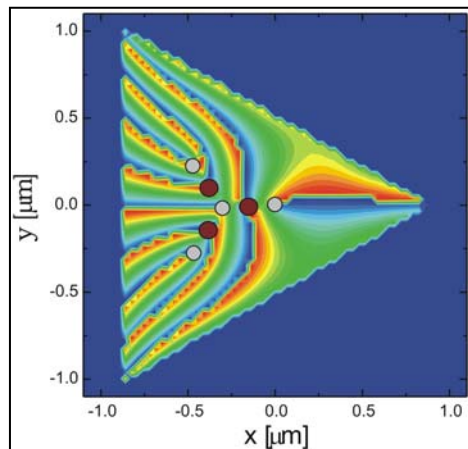
Cross-over from
Type I to Type II



Vortex State
Type II



3D Ginzburg-Landau Simulation



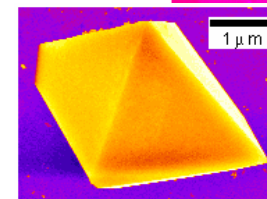
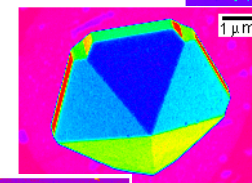
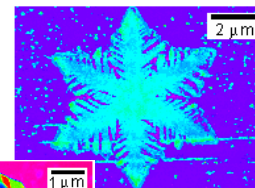
Co-existence of Abrikosov
and multi-quanta vortices

- Multi-quanta vortex,
vorticity = 2
- Abrikosov vortices

- Stability of vorticity as function
of size, shape, κ , and T

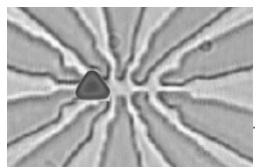
- Orientation dependence
& surface effects

- Enhanced pinning
at nano-vertices

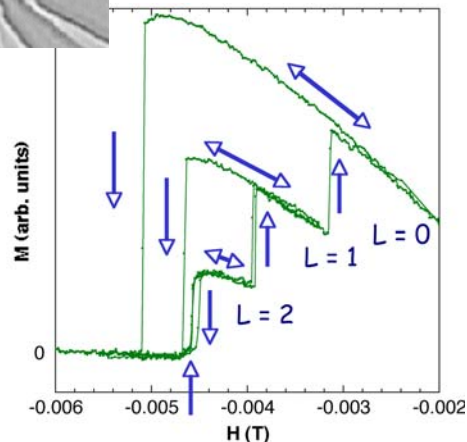


- Vortex nucleation
at vertices

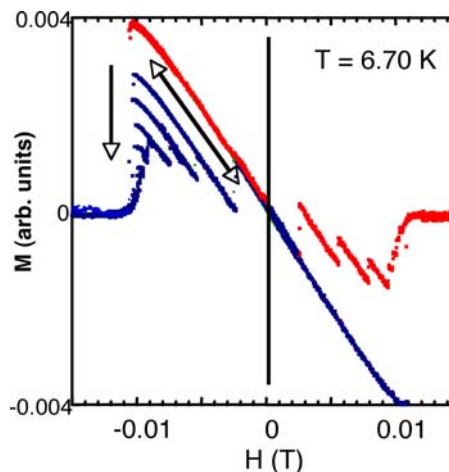
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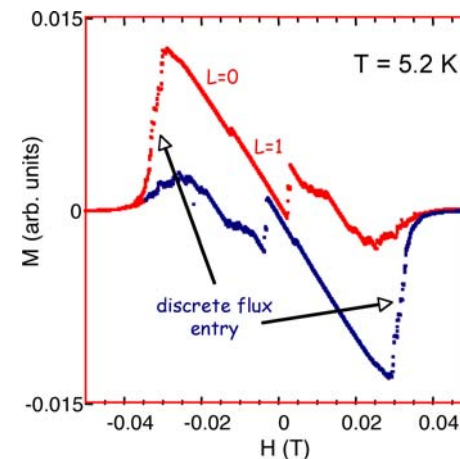
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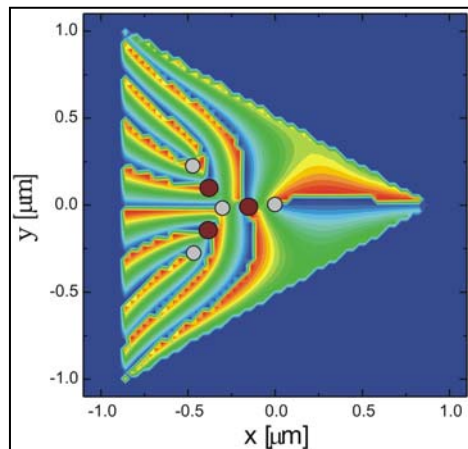
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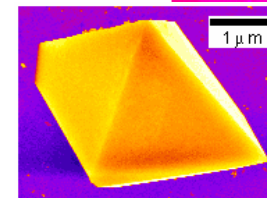
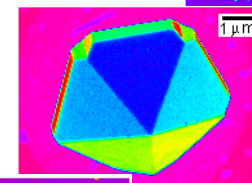
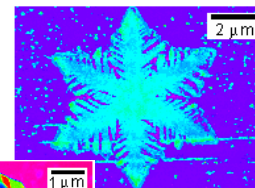
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